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Ozaki

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(54) **EQUIPMENT AND METHOD FOR BAND ALLOCATION**

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(73) Assignee: **NEC Corporation** (JP)

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H04J 3/16 (2006.01)

(52) **U.S. Cl.** **370/468**

(58) **Field of Classification Search** 370/468, 370/230, 278, 282, 222, 235, 516, 329, 390, 370/397, 401, 412, 470, 471, 907, 395.4, 370/395.42, 395.43

See application file for complete search history.

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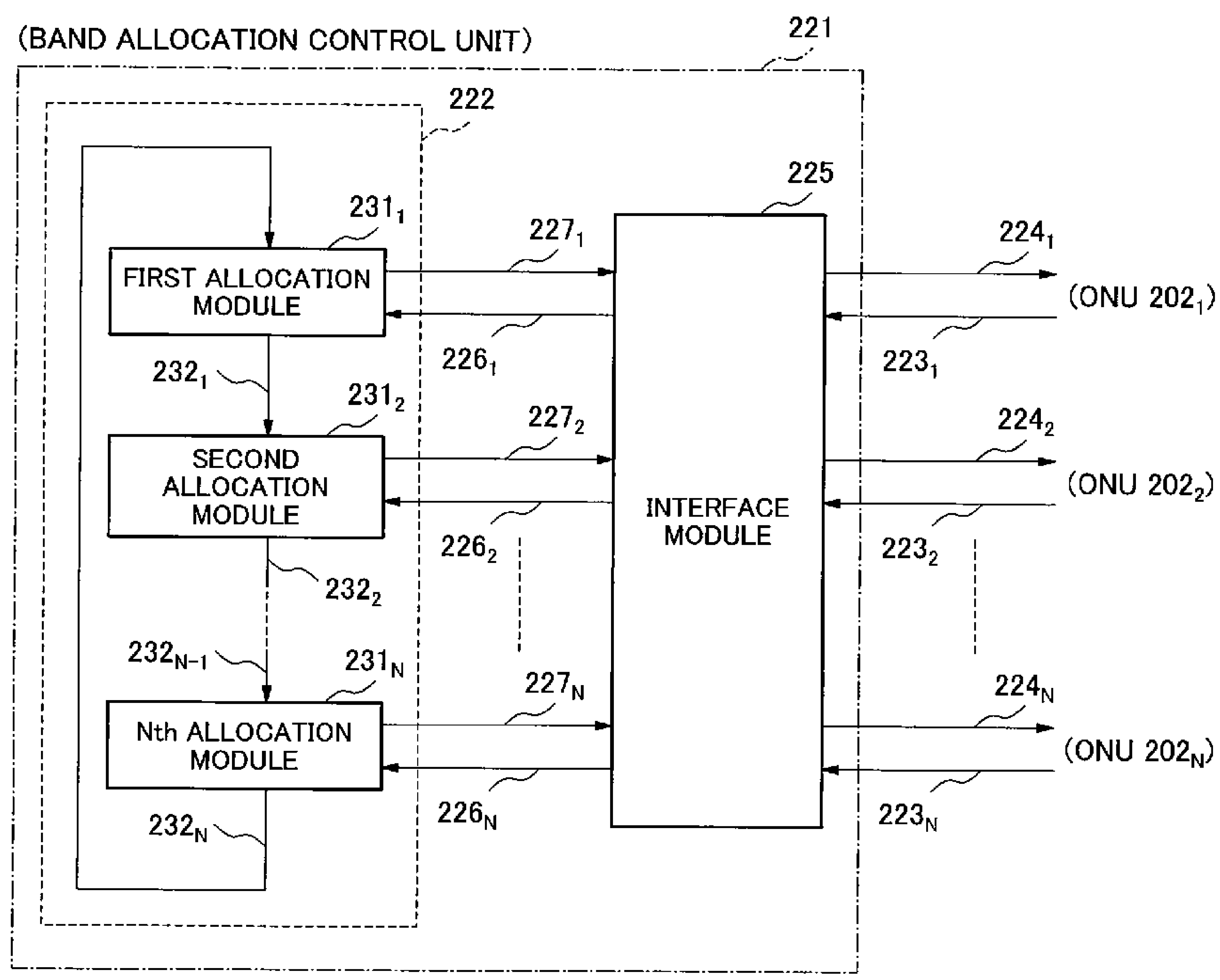
(57) **ABSTRACT**

A bandwidth allocation equipment in an optical line terminal, which allocates bandwidth for data to be transmitted from optical network units through an optical splitter, includes a transmit/receive unit and bandwidth allocation units. The transmit/receive unit receives an output request for requesting bandwidth allocation, and sends back a signal sending permission to the respective optical network units for specifying bandwidth to be allowed for transmitting the data in each service cycle. The bandwidth allocation units are connected to one another in a ring. Each bandwidth allocation unit is provided with corresponding to the optical network unit, and outputs the signal sending permission from the bandwidth allocation unit that has performed the last bandwidth allocation processing in the ring connection. The transmit/receive unit specifies the bandwidth allocation unit that performs the first bandwidth allocation processing by shifting one by one for each of the service cycles.

13 Claims, 15 Drawing Sheets



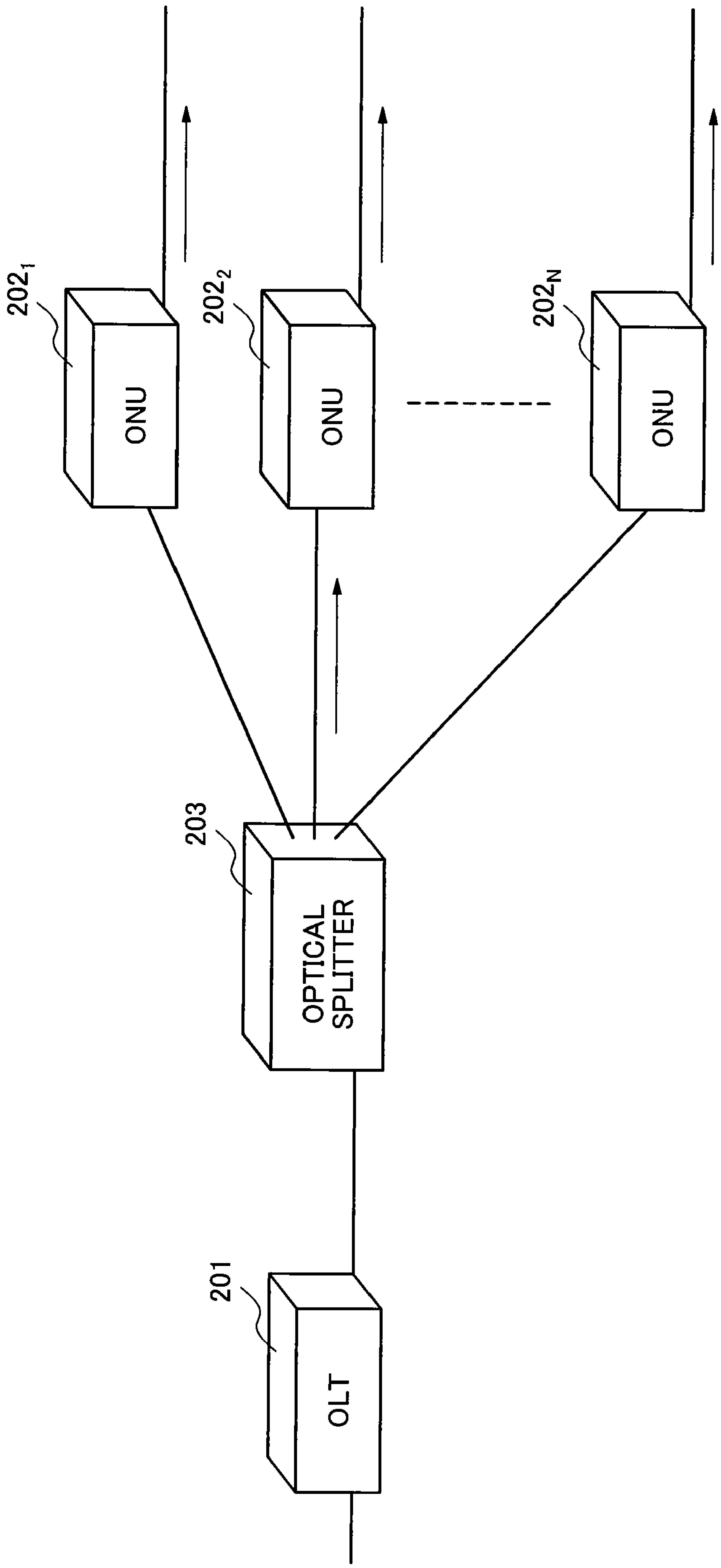


FIG.1

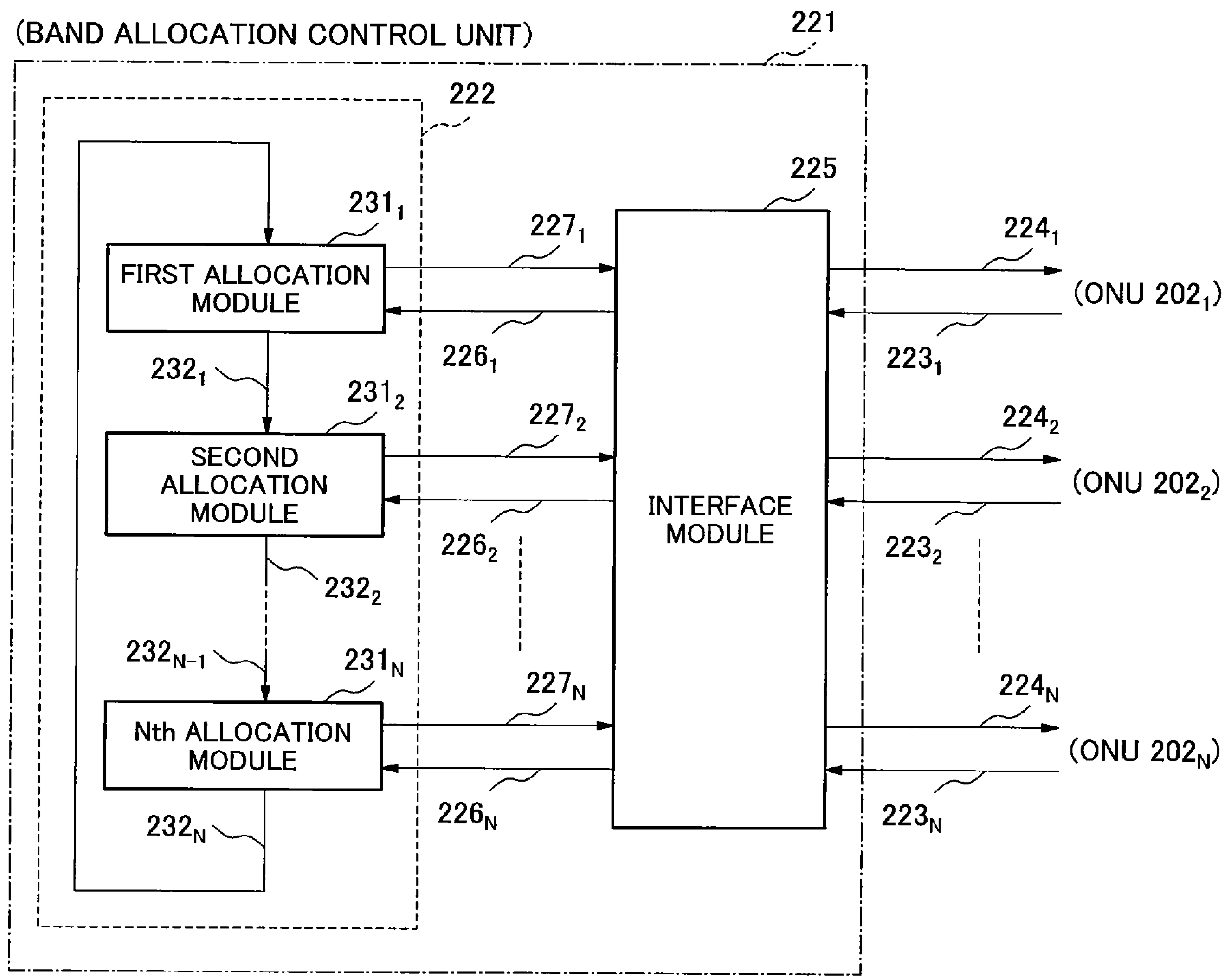

(BAND ALLOCATION CONTROL UNIT)
221
222
225
231_1
FIRST ALLOCATION MODULE
227_1
224_1
(ONU 202_1)
226_1
223_1
232_1
231_2
SECOND ALLOCATION MODULE
227_2
224_2
(ONU 202_2)
INTERFACE MODULE
226_2
223_2
232_2
232_{N-1}
231_N
Nth ALLOCATION MODULE
227_N
224_N
(ONU 202_N)
226_N
223_N
232_N

FIG.2

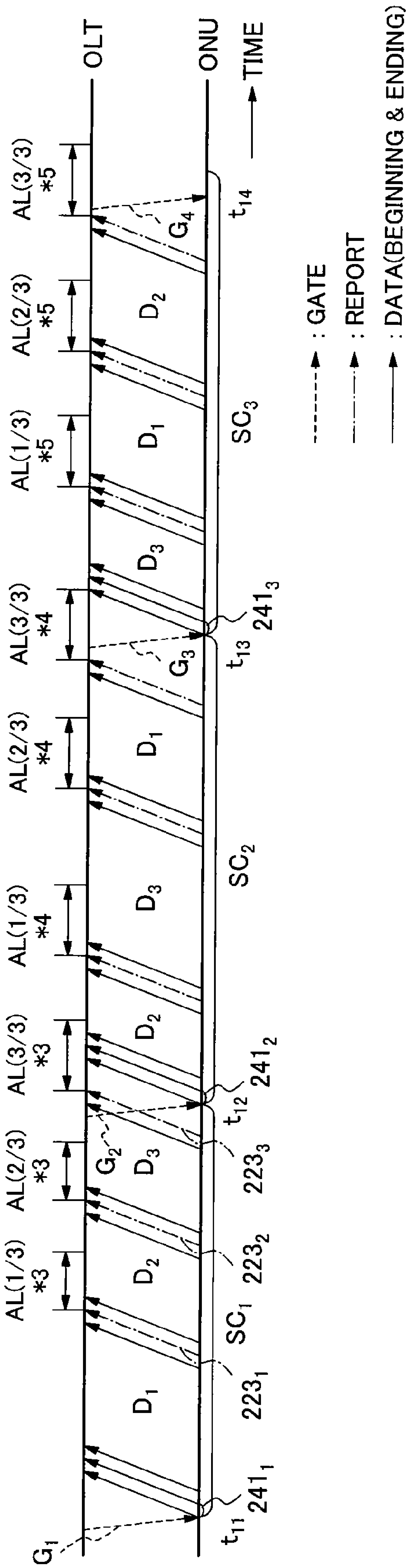

OLT
ONU
TIME
AL(1/3) *3
AL(2/3) *3
AL(3/3) *3
AL(1/3) *4
AL(2/3) *4
AL(3/3) *4
AL(1/3) *5
AL(2/3) *5
AL(3/3) *5
G_1
G_2
G_3
G_4
D_1
D_2
D_3
SC_1
SC_2
SC_3
t_{11}
t_{12}
t_{13}
t_{14}
241_1
241_2
241_3
223_1
223_2
223_3
: GATE
: REPORT
: DATA(BEGINNING & ENDING)

FIG.3

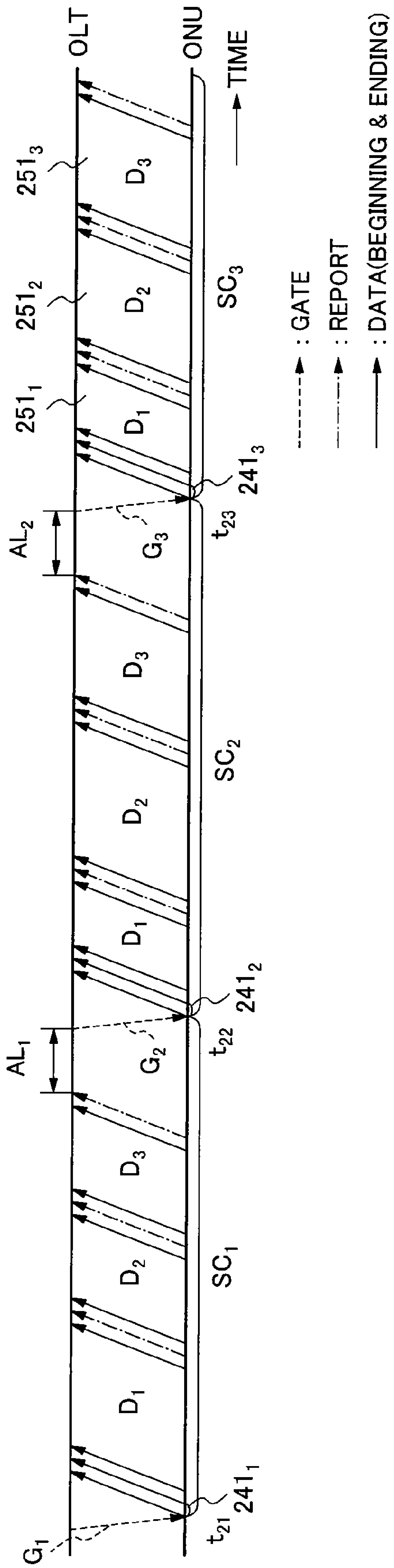


FIG.4
RELATED ART

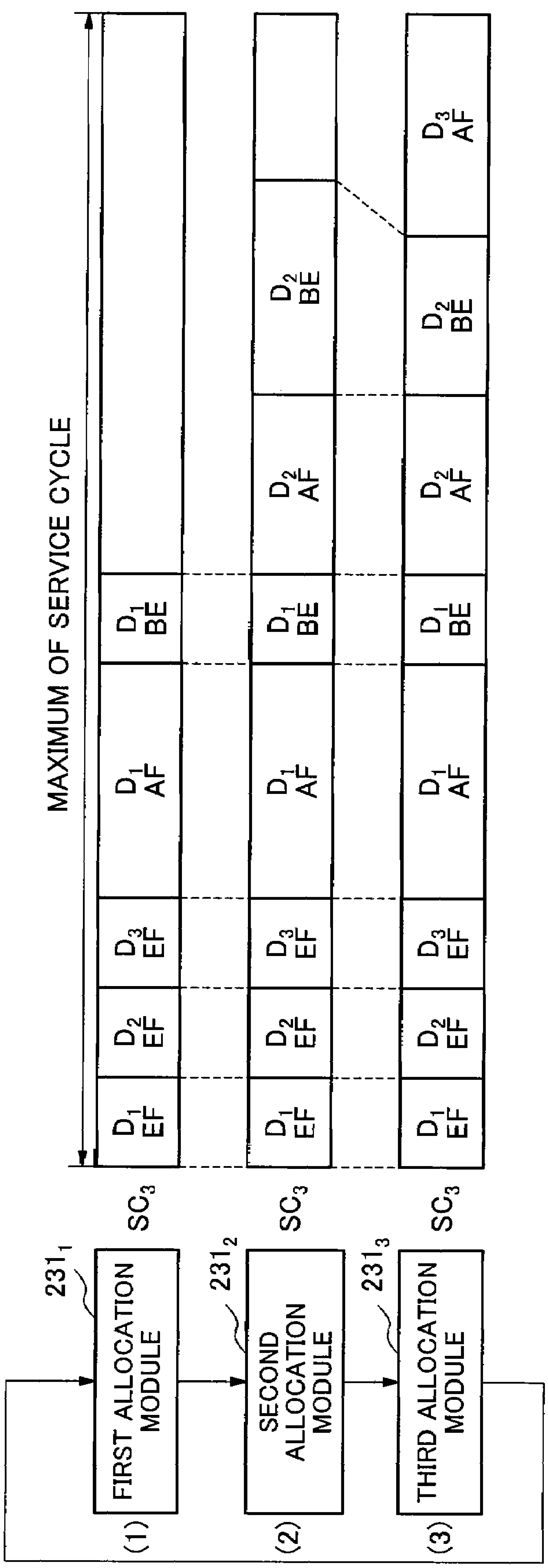

MAXIMUM OF SERVICE CYCLE
(1)
FIRST ALLOCATION MODULE
231₁
(2)
SECOND ALLOCATION MODULE
231₂
(3)
THIRD ALLOCATION MODULE
231₃
SC₃
D₁ EF
D₂ EF
D₃ EF
D₁ AF
D₁ BE
D₂ AF
D₂ BE
D₃ AF

FIG.5

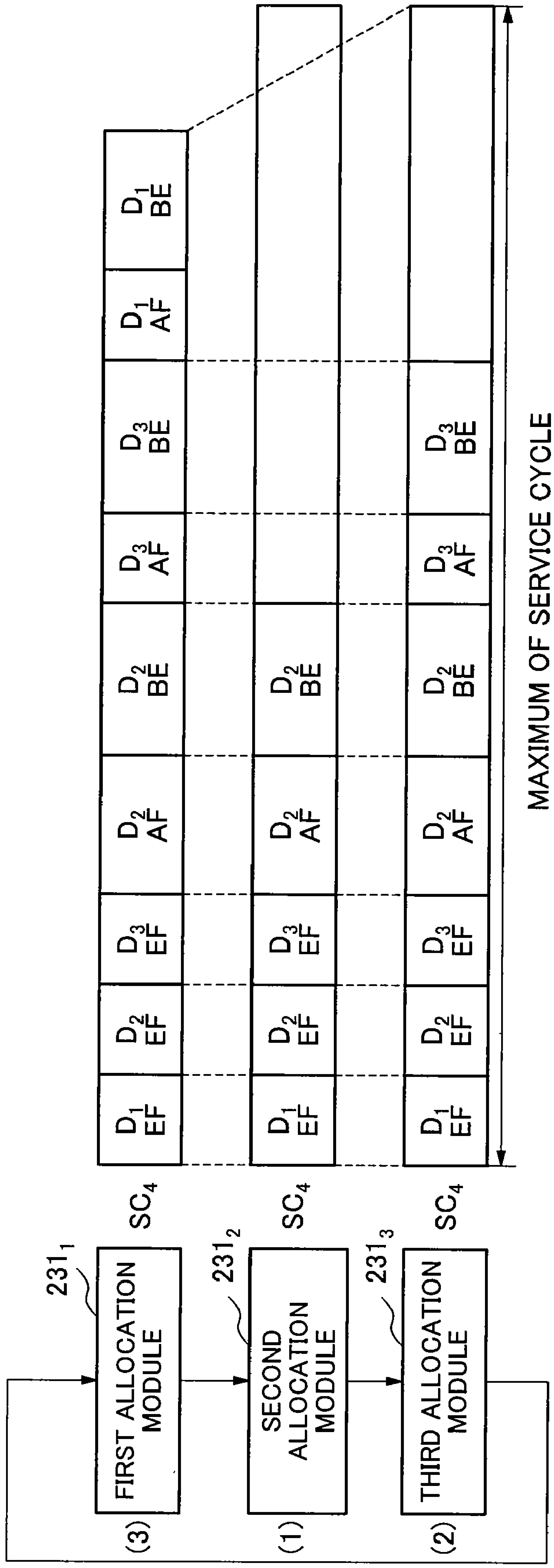

FIRST ALLOCATION MODULE
SECOND ALLOCATION MODULE
THIRD ALLOCATION MODULE
(3)
(1)
(2)
231_1
231_2
231_3
SC_4
D_1 EF
D_2 EF
D_3 EF
D_2 AF
D_2 BE
D_3 AF
D_3 BE
D_1 AF
D_1 BE
MAXIMUM OF SERVICE CYCLE

FIG.6

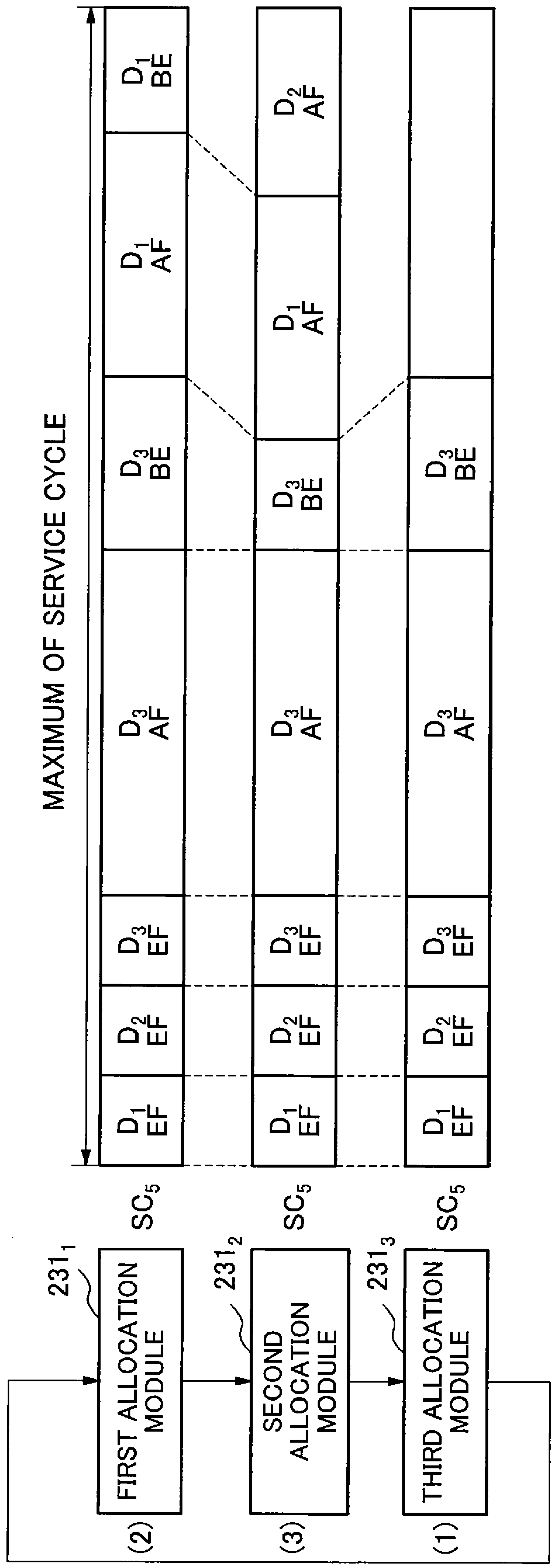
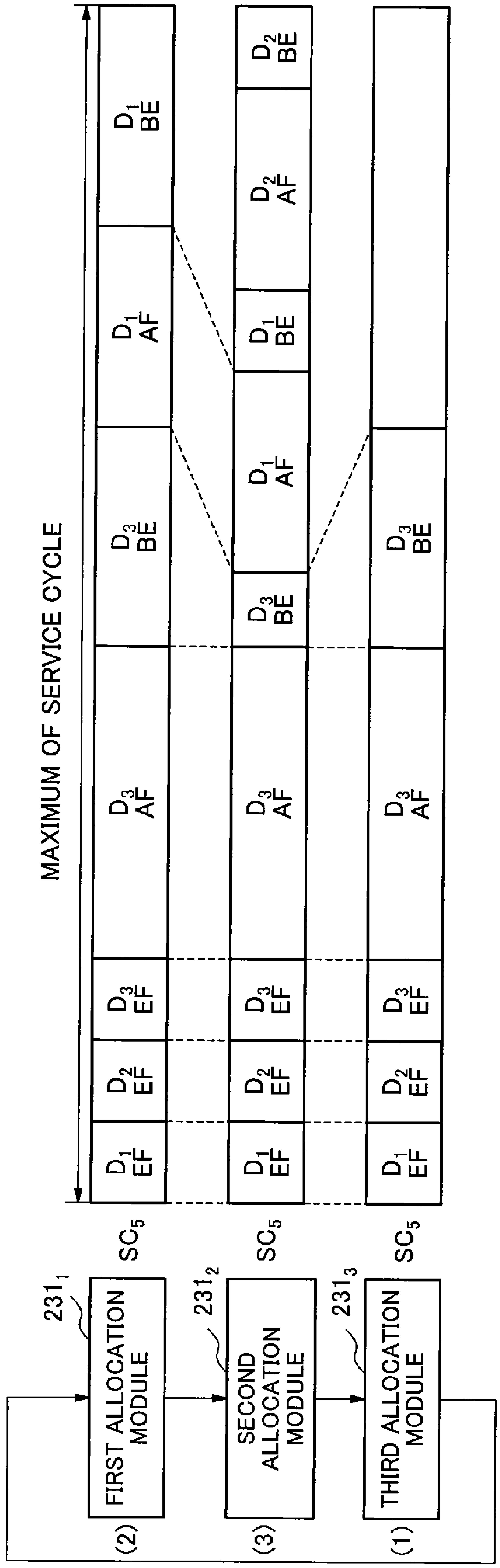

MAXIMUM OF SERVICE CYCLE
D1 EF
D2 EF
D3 EF
D3 AF
D3 BE
D1 AF
D1 BE
D2 AF
SC5
231 1
231 2
231 3
FIRST ALLOCATION MODULE
SECOND ALLOCATION MODULE
THIRD ALLOCATION MODULE
(2)
(3)
(1)

FIG.7



MAXIMUM OF SERVICE CYCLE
(1) THIRD ALLOCATION MODULE
(2) FIRST ALLOCATION MODULE
(3) SECOND ALLOCATION MODULE
231₁
231₂
231₃
SC₅
D₁ EF
D₂ EF
D₃ EF
D₃ AF
D₃ BE
D₁ AF
D₁ BE
D₂ AF
D₂ BE

FIG.8

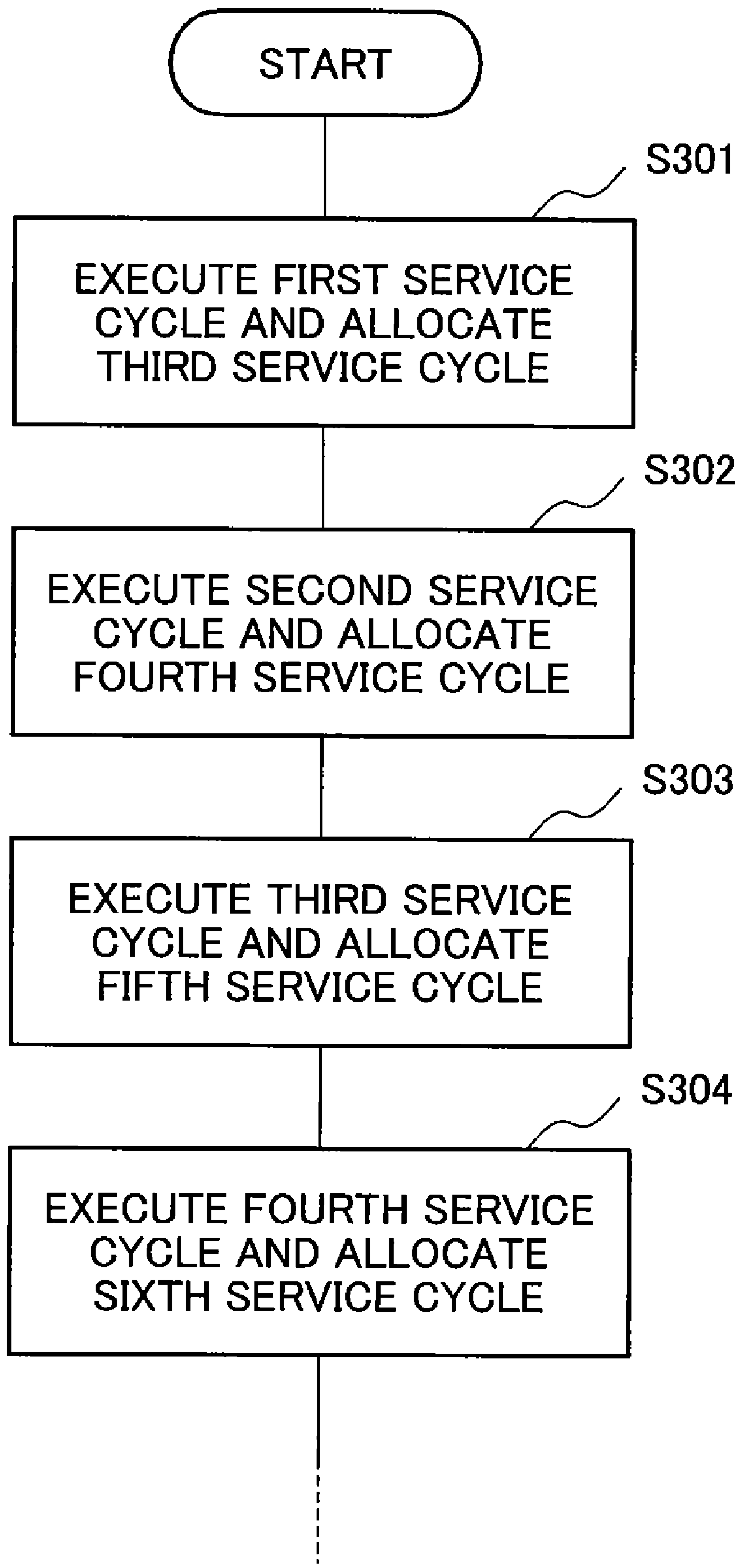

START
S301
EXECUTE FIRST SERVICE CYCLE AND ALLOCATE THIRD SERVICE CYCLE
S302
EXECUTE SECOND SERVICE CYCLE AND ALLOCATE FOURTH SERVICE CYCLE
S303
EXECUTE THIRD SERVICE CYCLE AND ALLOCATE FIFTH SERVICE CYCLE
S304
EXECUTE FOURTH SERVICE CYCLE AND ALLOCATE SIXTH SERVICE CYCLE

FIG.9

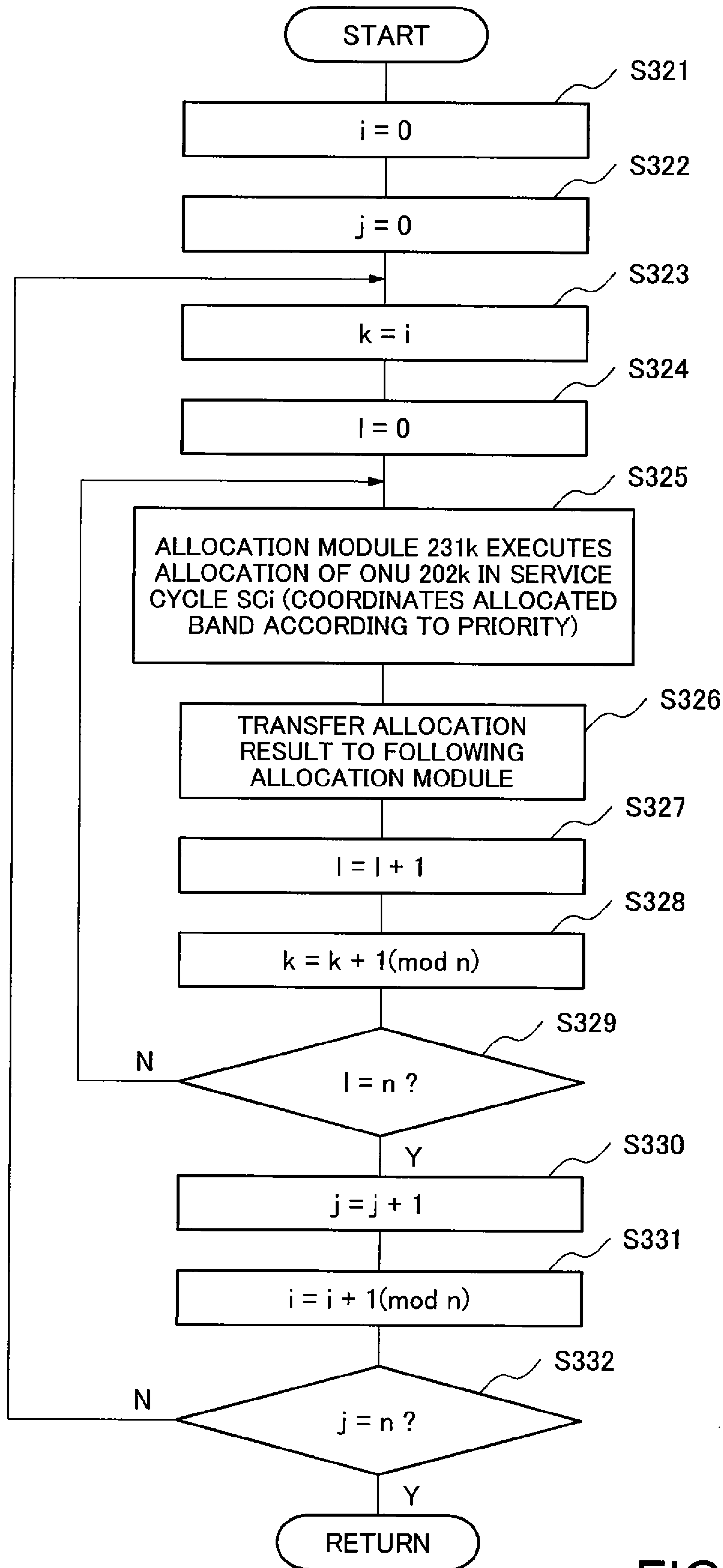

START
S321
i = 0
S322
j = 0
S323
k = i
S324
l = 0
S325
ALLOCATION MODULE 231k EXECUTES ALLOCATION OF ONU 202k IN SERVICE CYCLE SCi (COORDINATES ALLOCATED BAND ACCORDING TO PRIORITY)
S326
TRANSFER ALLOCATION RESULT TO FOLLOWING ALLOCATION MODULE
S327
l = l + 1
S328
k = k + 1(mod n)
S329
l = n ?
N
Y
S330
j = j + 1
S331
i = i + 1(mod n)
S332
j = n ?
N
Y
RETURN

FIG.10

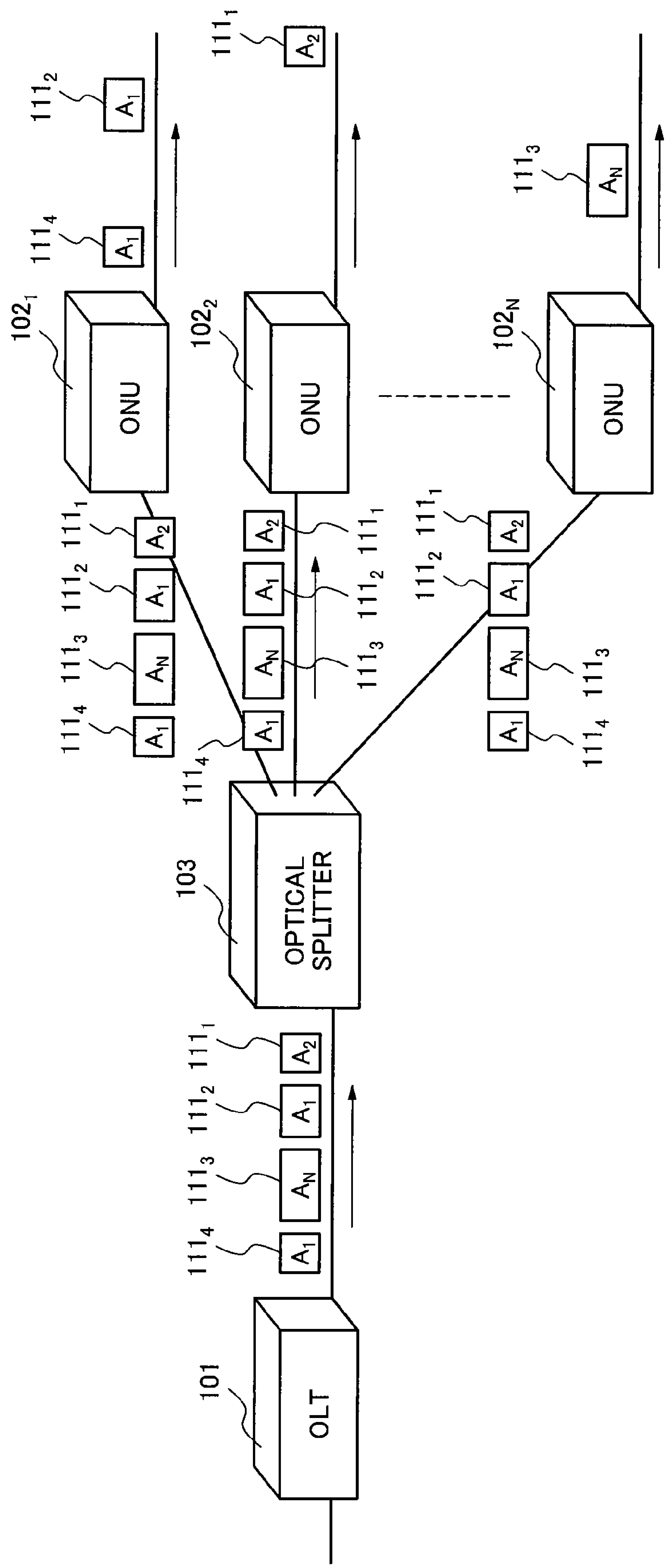


FIG.11
RELATED ART

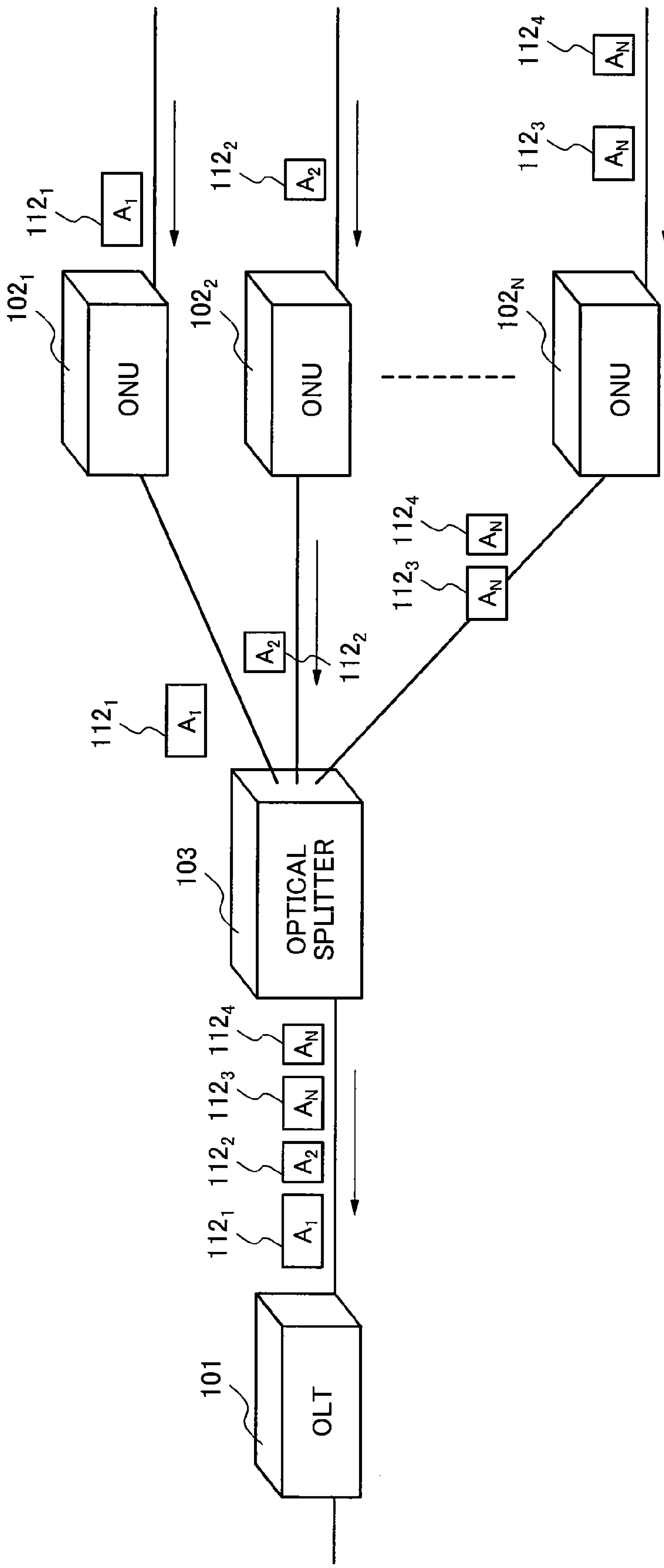


FIG.12
RELATED ART

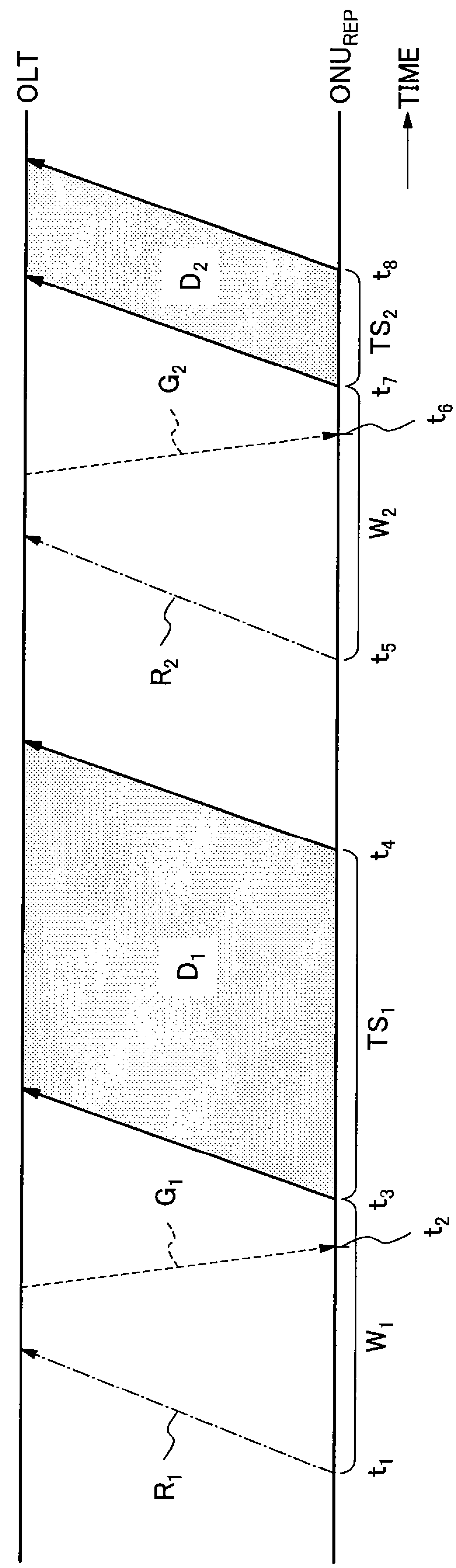


FIG.13
RELATED ART

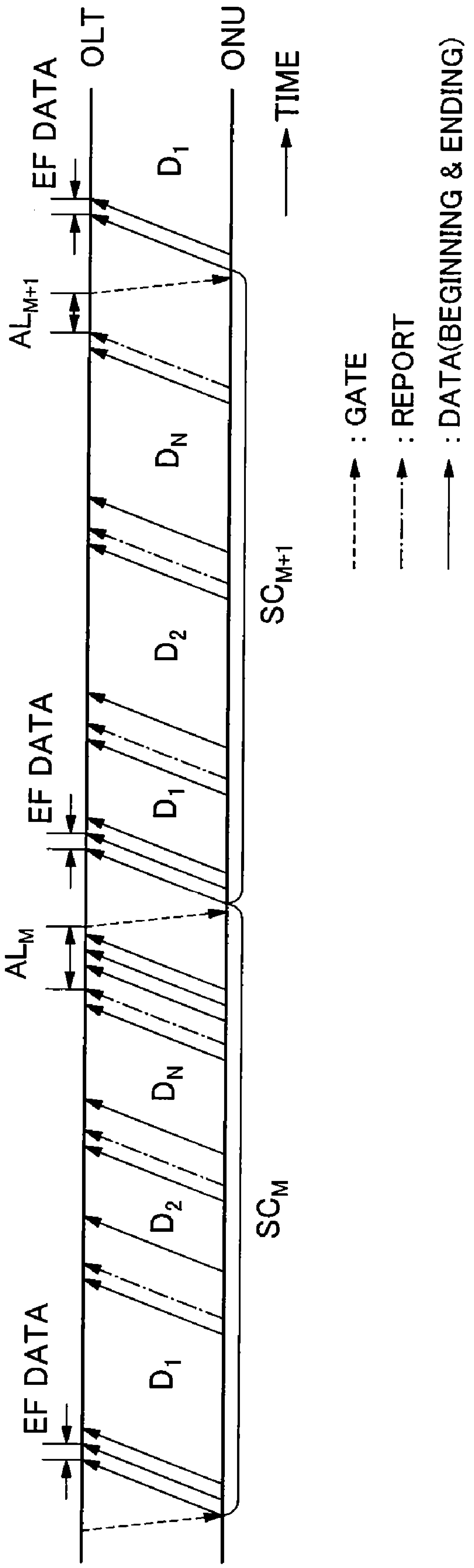


FIG.14
RELATED ART

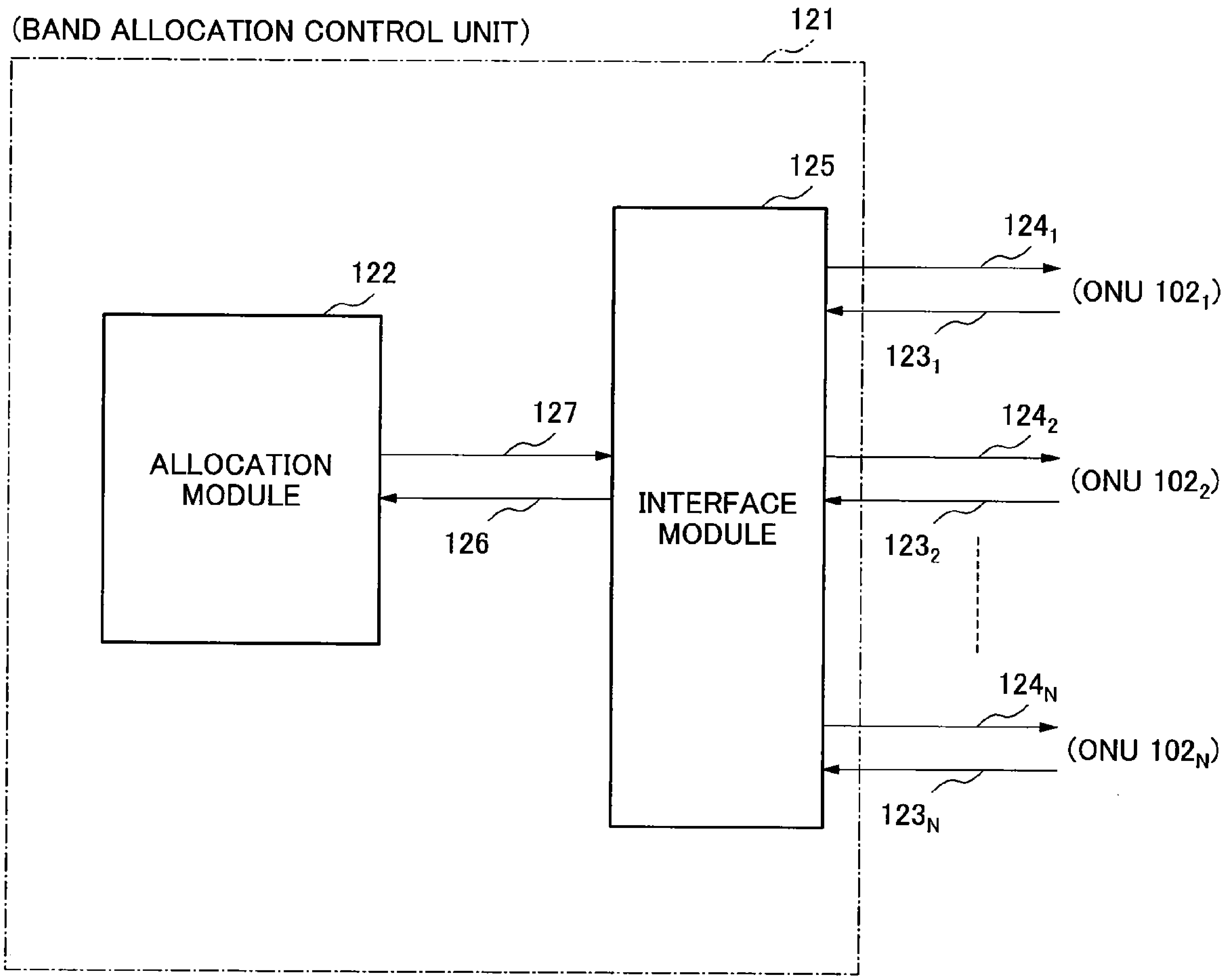


FIG.15
RELATED ART

EQUIPMENT AND METHOD FOR BAND ALLOCATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an equipment and a method for bandwidth allocation at an optical line terminal in the Passive Optical Network.

2. Description of the Related Art

The Internet is rapidly spreading and developing. Accordingly, large amount of data such as image data or video data is often communicated, raising an important issue of improving a communication line to a broadband to allow wideband access to the Internet. As a broadband access line, various types of technology have been put into practical use such as ADSL (Asymmetric Digital Subscriber Line) using existing telephone lines, or a cable modem using a coaxial line of CATV (Cable TeleVision) as a network line. However, for realization of high-speed and high-quality communication environment, it is desired that a communication line is further improved to a wideband. In such status, a PON (Passive Optical Network) as a network using optical fiber is getting attention.

FIG. **11** illustrates a PON configuration and downstream frame transmission. The PON includes an OLT (Optical Line Terminal) **101** located in a station (not shown), first to Nth ONUs (Optical Network Units) $\mathbf{102}_1$-$\mathbf{102}_N$ located in respective end users' homes and an optical splitter **103** that splits or joins signals among the ONUs. Each personal computer (not shown) in the end user's home connects to the network via any of the ONUs $\mathbf{102}_1$-$\mathbf{102}_N$, the optical splitter **103** and the OLT **101**.

In the above PON, upstream and downstream signals are wavelength-multiplexed into single, bi-directional optical fiber for transmission. For example, the wavelength of an upstream signal is 1.3 μm in many cases, while the wavelength of a downstream signal is 1.5 μm. As illustrated in FIG. **11**, a downstream signal is broadcast from the OLT **101** to all ONUs $\mathbf{102}_1$-$\mathbf{102}_N$. The broadcast means simultaneous transmission to all nodes in the same segment. In this case, the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ check destinations of transmitted frames and capture frames only addressed to themselves.

For example, assume that the OLT **101** transmits frames $\mathbf{111}_1$, $\mathbf{111}_2$, $\mathbf{111}_3$ and $\mathbf{111}_4$ having destination A_2, A_1, A_N and A_1, respectively in that order. In this case, the optical splitter **103** simply splits and transmits the frames $\mathbf{111}_1$, $\mathbf{111}_2$, $\mathbf{111}_3$ and $\mathbf{111}_4$ to all ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ in that order. Assume that a destination to the first ONU $\mathbf{102}_1$ is A_1, a destination to the second ONU $\mathbf{102}_2$ is A_2, and a destination to the Nth ONU $\mathbf{102}_N$ is A_N. In this case, the second ONU $\mathbf{102}_2$ first captures the frame $\mathbf{111}_1$ having the destination A_2. Next, the first ONU $\mathbf{102}_1$ captures the frame $\mathbf{111}_2$ having the destination A_1. Then, the Nth ONU $\mathbf{102}_N$ captures the frame $\mathbf{111}_3$ having the destination A_N. Finally, the first ONU $\mathbf{102}_1$ captures the frame $\mathbf{111}_4$ having the destination A_1.

FIG. **12** illustrates upstream frame transmission in a PON identical to that of FIG. **11** in configuration. Upstream frames transmitted from the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ join at the optical splitter **103**. At the optical splitter **103**, it is necessary to avoid a temporal overlap of frames and collision of signals. For this necessity, time division multiplexing communication is performed for the frames sent from the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ not to overlap. In the time division multiplexing communication, the OLT **101** coordinates an output request (REPORT) reported from the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$. OLT **101** calculates transmission time based on distances between the OLT **101** and each of the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$. Then, OLT **101** grants signal sending permissions (GATEs) that specify transmission timing to some of the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ that have reported the output requests.

Each of the output requests (REPORTs) reported by the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ includes the state of a queue, i.e. the length of the queue in a buffer memory (not shown) for storing signals to be transmitted for information. According to the length of a frame, the OLT **101** can specify the timing to permit transmission of the frame. A signal sending permission (GATE) output by the OLT **101** includes the time to start sending and the time period to continue sending that depend on the priority of a frame subjected to an output request (REPORT).

Some of the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ that have performed output requests (REPORTs) (hereinafter called "ONUs $\mathbf{102}_{REP}$") send upstream signals according to signal sending permissions (GATEs) sent to them. In other words, bandwidth allocation for the upstream signals from each ONU $\mathbf{102}_{REP}$ is accomplished as allocation of a time slot for upstream signal transmission.

FIG. **13** illustrates a conventional exchange of the above described output request (REPORT) and of the signal sending permission (GATE) to it. In this diagram, the signal exchange between the OLT **101** and the single ONU $\mathbf{102}_{REP}$ is illustrated using a time axis (time) as the axis of abscissas. First, the ONU $\mathbf{102}_{REP}$ sends an output request R_1 at time t_1 on the occurrence of a signal to be transmitted. When the OLT **101** receives the request, it sends back a signal sending permission G_1 and the ONU $\mathbf{102}_{REP}$ receives the permission at time t_2. The ONU $\mathbf{102}_{REP}$ starts sending data D_1 in a predetermined time slot TS_1 at time t_3. A period between the time t_1 and the time t_3 is waiting time W_1. The time when the sending of the data D_1 completes is time t_4.

The ONU $\mathbf{102}_{REP}$ sends a second output request R_2 at time t_5 after the time t_4. The OLT **101** sends back a signal sending permission G_2 and the ONU $\mathbf{102}_{REP}$ receives the permission at time t_6. The ONU $\mathbf{102}_{REP}$ starts sending data D_2 in a predetermined time slot TS_2 at time t_7 after waiting time W_2. The time when the sending of the data D_2 completes is time t_8. The data D_1, D_2 . . . are transmitted by repeating the above processing.

Each of the output requests R_2, R_3, . . . following to the first request R_1 can be transmitted piggyback at the ends of the data D_1, D_2, . . . that are previously sent, respectively. For example, if the second output request R_2 is ready to be output at the time t_4, the request R_2 can be transmitted without waiting till the time t_5. In this case, the time t_5 is identical to the time t_4.

Next, communication between the ONUs $\mathbf{102}_1$, $\mathbf{102}_2$, . . . , $\mathbf{102}_N$ and the OLT **101** shown in FIG. **11** is described with reference to FIG. **14**. A cycle that transmission of upstream signal transmitted from ONU to OLT makes a circuit of all ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ is referred to as a Service Cycle (SC). Assume that N equals three. FIG. **14** shows contents of an Mth service cycle SC_M and the next (M+1)th service cycle SC_{M+1} in detail. Usually, the length of a service cycle SC does not need to be always constant, but may change dynamically depending on the status of output requests by the respective ONUs $\mathbf{102}_1$-$\mathbf{102}_N$.

An Ethernet (R) PON for transmitting Ethernet packets via a PON is standardized according to the IEEE (The Institute of Electrical and Electronics Engineers, Inc.) 802.3ah. The IEEE 802.3ah defines frame formats for an output request (REPORT) message and a signal sending permission (GATE) message. However, since it does not define an upstream bandwidth allocation method or algorithm, these can be defined in equipment design as necessary.

In the Mth service cycle SC_M shown in FIG. **14**, EF (Expedited Forwarding) data (DATA) of a class for guaranteeing a delay and a bandwidth is transmitted first, as described below. Then, the data D_1 of the first ONU $\mathbf{102}_1$ is transmitted to the OLT **101**, and the data D_2 of the second ONU $\mathbf{102}_2$ is transmitted to the OLT **101** in the next time slot. Finally, the data D_N of the Nth ONU $\mathbf{102}_N$ is transmitted to the OLT **101**. In this way, when the last data D_N in the Mth service cycle SC_M is transmitted to the OLT **101**, traffic allocation AL_M in the next service cycle is performed. In the (M+1)th service cycle SC_{M+1}, the data D_1 of the first ONU $\mathbf{102}_1$ is similarly transmitted to the OLT **101** after the EF data, and the data D_2 of the second ONU $\mathbf{102}_2$ is transmitted to the OLT **101** in the next time slot. Finally, the data D_N of the Nth ONU $\mathbf{102}_N$ is transmitted to the OLT **101**. In the last interval in the (M+1)th service cycle SC_{M+1}, traffic allocation AL_{M+1} in the next service cycle is performed. Subsequent allocations are performed in the same way as above.

Now, traffic classification is described. The traffic classification is performed for upstream signals to transmit frames corresponding to a plurality of services according to priorities. Each class has a corresponding priority. For example, in the DiffServe (Differentiated Services) of the IETF (The Internet Engineering Task Force), in addition to the EF shown in FIG. **14**, classes of AF (Assured Forwarding) and BE (Best Effort) are defined. The EF is a class for guaranteeing a delay and bandwidth and of the highest priority. The AF is a class for not guaranteeing a delay but guaranteeing a bandwidth. The BE is a class for not guaranteeing a delay or a bandwidth and of the lowest priority. Representative service applications of the EF, AF, and BE classes include VoIP (Voice over IP), file transfer and usual Internet access, respectively.

There are several algorithms for bandwidth allocation. There is an algorithm called D1 for the PON (for example, see Y. Luo et al., "Bandwidth Allocation for Multiservice Access on EPONs," IEEE Communications Magazine 2005 February s16-s21) The D1 algorithm determines in advance a maximum value of a service cycle SC and allocates a bandwidth so as not to exceed the maximum value. First, the EF, a class for guaranteeing both a delay and a bandwidth in an output request (REPORT) by each of the ONU $\mathbf{102}_1$, the ONU $\mathbf{102}_2$ and the ONU $\mathbf{102}_N$ is assigned a fixed bandwidth. The remaining bandwidth is allocated to the AF data, a class for not guaranteeing a delay but guaranteeing a bandwidth in an output request (REPORT) by each of the ONU $\mathbf{102}_1$, the ONU $\mathbf{102}_2$ and the ONU $\mathbf{102}_N$. In this allocation, if a total sum of requested AF data is equal to or less than the remaining bandwidth of a service cycle after allocating the EF data, all the requested AF data are assigned.

After the AF data is assigned, if further band width remains in the service cycle SC, the BE data, a class for not guaranteeing a delay or a bandwidth in the output request is allocated. If a total sum of the requested AF data exceeds the remaining bandwidth after the EF data is assigned, the ONUs **102** that requested the AF data transmission are equally assigned the AF data. The BE data is not assigned since the remaining bandwidth is depleted by the ONU **102**.

The bandwidth calculation and allocation are performed after the output requests (REPORTs) are notified from all the ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ to the OLT **101**. Based on the bandwidth calculation and allocation, the OLT sends a signal sending permission (GATE) to the relevant ONUs **102**.

FIG. **15** illustrates a configuration of bandwidth allocation control unit used in a conventional OLT. A bandwidth allocation control unit **121** includes an allocation module **122** that allocates bandwidth and an interface module **125**. The interface module **125** receives output requests (REPORTs) $\mathbf{123}_1$-$\mathbf{123}_N$ and transmits signal sending permissions (GATEs) $\mathbf{124}_1$-$\mathbf{124}_N$ from/to the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$. The interface module **125** receives the state of a buffer memory for storing signals to be transmitted by the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$, as output requests $\mathbf{123}_1$-$\mathbf{123}_N$ respectively. When the allocation module **122** has allocated bandwidth, the interface module **125** transmits the result as the signal sending permissions $\mathbf{124}_1$-$\mathbf{124}_N$ to the ONUs $\mathbf{102}_1$-$\mathbf{102}_N$, respectively. The allocation module **122** performs the allocation according to the above described D1 algorithm. The interface module **125** notifies the allocation module **122** of queue state signals **126** indicating the states of queues in buffer memories in the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$, i.e. queue lengths. The interface module receives allocation complete signals **127** corresponding to the notification and sends the signal sending permissions $\mathbf{124}_1$-$\mathbf{124}_N$.

Since the D1 algorithm is relatively simple, D1 is easily implemented in a small-scale PON. Bandwidth is allocated evenly among the ONUs $\mathbf{102}_1$-$\mathbf{102}_N$.

However, the conventional algorithm has a problem of system scalability. That is, in this algorithm, after the output requests $\mathbf{123}_1$-$\mathbf{123}_N$ are collected from the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$, the allocation is performed intensively till the next service cycle SC starts. Accordingly, if the number of ONUs **102** increases, the allocation module **122** is assigned excessive loads. By this reason, in a large-scale PON, the bandwidth allocation control unit **121** needs an expensive and high-speed integrated circuit or a CPU, which raises the cost of a system. Additionally, if sufficient time is allowed for the bandwidth allocation to solve this problem, starting time of the service cycle SC delays and bandwidth is wasted. As a result, there is a problem that the bandwidth allocation is constrained particularly for the AF data and BE data classes and system performance degrades.

An object of the present invention is to provide an equipment and a method for bandwidth allocation in an optical line terminal that can allocate bandwidth evenly among respective ONUs constituting a PON and does not cause a decrease of bandwidth efficiency for a large number of ONUs.

SUMMARY OF THE INVENTION

According to an aspect of the present invention, a bandwidth allocation equipment in an optical line terminal which allocates bandwidth for data to be transmitted from a plurality of optical network units through an optical splitter, said equipment includes: a transmit/receive unit that receives an output request for requesting bandwidth allocation to the data from the respective optical network units, and sends back a signal sending permission to the respective optical network units for specifying bandwidth to be allowed for transmitting the data in each service cycle as a unit period for the data transmission; and a plurality of bandwidth allocation units, each bandwidth allocation unit is provided with corresponding to the optical network unit for performing bandwidth allocation processing in accordance with the output request for the data to be transmitted from the corresponding optical network unit, and each of bandwidth allocation units are connected to one another in a ring to perform the bandwidth allocation processing one by one for corresponding optical network unit, and outputs the signal sending permission to the transmit/receive unit from the bandwidth allocation unit that has performed the last bandwidth allocation processing in the ring connection. Said transmit/receive unit specifies the bandwidth allocation unit that performs the first bandwidth allocation processing by shifting the bandwidth allocation unit one by one for each of the service cycles.

The present invention relates to a bandwidth allocation equipment that allocates bandwidth for data sent from each Optical Network Unit (ONU) to the Optical Line Terminal (OLT) through the optical splitter in consideration to the priorities. The bandwidth allocation equipment comprises a transmit/receive unit for communicating with each optical network unit, and receives an output request as a data transmission request from each optical network unit. The bandwidth allocation equipment sends back transmittable data types in a service cycle as a unit period for the data transmission and bandwidth to be allocated to the data as a signal sending permission to each optical network unit. The output request decides time-divisioned bandwidth allocation in the service cycle as the unit period wherein each optical network unit transmits data to the optical line terminal. If data transmission beyond the Maximum of Service Cycle is requested, bandwidth allocated to each of the optical network units must be controlled. In the present invention, an ONU (Optical Network Unit) bandwidth allocation unit provided for each of the optical network units allocates bandwidth depending on the priorities. The ONU bandwidth allocation units are located in a ring, and even processing is possible by shifting ONU bandwidth allocation units that allocates bandwidth for each service cycle. Even if there are many optical network units, rapid processing is possible since each ONU bandwidth allocation unit can only control bandwidth allocation for the optical network unit assigned to it. As a result, the bandwidth allocation control is sped up, causing no decrease in bandwidth efficiency.

As described above, according to the present invention, the ONU bandwidth allocation unit is provided to send data from each optical network unit to the optical line terminal through the optical splitter. With the bandwidth allocation unit, bandwidth allocation can be processed depending on the status of respective optical network units. If the optical network units increase, the ONU bandwidth allocation units can increase accordingly, therefore there is no redundancy in a configuration of a communication system. If there is a plurality of ONU bandwidth allocation units and some of them suffer problems, other optical network units can substitute for the processing, so that reliability of the communication system improves.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary features and advantages of the present invention will become apparent from the following detailed description when taken with the accompanying drawings in which:

FIG. **1** is a system configuration illustrating an overview of a PON in one embodiment of the present invention;

FIG. **2** is a block diagram illustrating a configuration of a bandwidth allocation control unit in the embodiment;

FIG. **3** is a timing diagram illustrating a way that three ONUs communicate with an OLT in the embodiment;

FIG. **4** is a timing diagram illustrating a conventional way that three ONUs communicate with an OLT in contrast to the embodiment;

FIG. **5** is a diagram illustrating transition of bandwidth allocation by each allocation module in bandwidth allocation control in a service cycle SC_3 in the embodiment;

FIG. **6** is a diagram illustrating transition of bandwidth allocation by each allocation module in bandwidth allocation control in a service cycle SC_4 in the embodiment;

FIG. **7** is a diagram illustrating transition of bandwidth allocation by each allocation module in bandwidth allocation control in a service cycle SC_5 in the embodiment;

FIG. **8** is another example of diagram illustrating transition of bandwidth allocation in a service cycle SC_5 in the embodiment;

FIG. **9** is a flow diagram illustrating an overview of bandwidth allocation control unit in the embodiment;

FIG. **10** is a flow diagram illustrating further specific control of bandwidth allocation control unit;

FIG. **11** is a diagram illustrating a PON configuration and downstream frame transmission;

FIG. **12** is a diagram illustrating a PON configuration and upstream frame transmission;

FIG. **13** is a diagram illustrating a conventional exchange of output requests and signal sending permissions to them;

FIG. **14** is a diagram illustrating a conventional way that three ONUs communicate with an OLT; and

FIG. **15** is a block diagram illustrating a configuration of bandwidth allocation control unit used in a conventional OLT.

DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

The present invention will be described in detail in the following embodiment.

Embodiment 1

FIG. **1** illustrates an overview of a PON in one embodiment of the present invention. An OLT **201** in the present embodiment connects to first to Nth ONUs $\mathbf{202}_1$-$\mathbf{202}_N$ located correspondingly to end users' homes respectively via an optical splitter **203**. The OLT **201** connects to a communication network (not shown) such as the Internet. The first to Nth ONUs $\mathbf{202}_1$-$\mathbf{202}_N$ connect to communication terminals such as personal computers (not shown). The first to Nth ONUs $\mathbf{202}_1$-$\mathbf{202}_N$ and the optical splitter **203** have substantially identical configurations to those of the first to Nth ONUs $\mathbf{102}_1$-$\mathbf{102}_N$ and the optical splitter **103** shown in FIG. **11**. These configurations are not further described herein. In the present embodiment, a bandwidth allocation control unit of the OLT **201** differs from the bandwidth allocation control unit **121** shown in FIG. **15**. Other components of the OLT **201** are substantially identical to those of the OLT **101** shown in FIG. **11**.

FIG. **2** illustrates a configuration of a bandwidth allocation control unit in the present embodiment. A bandwidth allocation control unit **221** includes a group of allocation modules **222** that allocate bandwidth, an interface module **225** for transmitting/receiving output requests (REPORTs) $\mathbf{223}_1$-$\mathbf{223}_N$ and signal sending permissions (GATEs) $\mathbf{224}_1$-$\mathbf{224}_N$ to/from the first to Nth ONUs $\mathbf{202}_1$-$\mathbf{202}_N$. The bandwidth allocation control unit **221** includes a CPU (Central Processing Unit) (not shown), storage media such as a ROM (Reed Only Memory) that store control programs, and a working memory such as a RAM (Random Access Memory) for temporality storing various types of data when the CPU executes the control programs. Some or all of the above components can be replaced with hardware.

The interface module **225** receives the states of queues, i.e. lengths of the queues in said buffer memory for storing signals to be transmitted by the first to Nth ONUs $\mathbf{202}_1$-$\mathbf{202}_N$, as output requests $\mathbf{223}_1$-$\mathbf{223}_N$ respectively. When the group of allocation modules **222** allocates bandwidth, the interface module **225** transmits the result as signal sending permissions

224_1-224_N to the first to Nth ONUs 202_1-202_N. This operation is similar to that of the conventional interface module **125** shown in FIG. **15**.

A first to Nth allocation modules 231_1-231_N connect to one another in a ring, and perform serial distributed processing to allocate bandwidth in a distributed manner in each allocation module and output allocation complete signals **227** to the interface module **225**. For example, in case of processing that begins at the first allocation module 231_1 and completes the allocation in one cycle at the last Nth allocation module 231_N, when the first allocation module 231_1 completes the allocation processing in the allocation module based on a queue state signal 226_1 received from a first ONU 202_1, it outputs an allocation result signal 232_1 being a temporary allocation result to the second allocation module 231_2 connected to it. The details are described below. The second allocation module 231_2 performs the allocation processing based on a queue state signal 226_2 received from the second ONU 202_2 and an allocation result signal 232_1 supplied from the first allocation module 231_1, and outputs an allocation result signal 232_2 being the temporary allocation result to the third allocation module 231_3. In the following processing, the Nth allocation module 231_N similarly performs the allocation process based on the queue state signal 226_N received from an Nth ONU 202_N and an allocation result signal 232_{N-1} supplied from the (N−1)th allocation module 231_{N-1}, then outputs the allocation complete signal 227_N to the interface module **225**. In the next processing cycle, the processing starts at the second allocation module 231_2, the allocation processing in one cycle completes at the first allocation module 231_1 next to the Nth allocation module 231_N. In this case, the first allocation module 231_1 outputs the allocation complete signal 227_1 to the interface module **225**. In this way, according to the present invention, the allocation processing in each cycle is executed in the first to Nth allocation modules 231_1-231_N, allocation modules other than the last stage supply the result of the allocation in the allocation module as an allocation result signal being temporary allocation result to the next allocation module, and the allocation processing unit of the last stage outputs the allocation complete signal **227** as information that the allocation in the cycle has been completed to the interface module **225**. The allocation module as the initial stage for starting processing in each cycle is set by sequential shifting.

Next, the bandwidth allocation in the group of allocation modules **222** is described in detail. For simplicity, the number N of ONUs constituting a system is three, and bandwidth allocation control for the first to third ONUs 202_1-202_3 is described. A cycle of data transmission by the first to third ONUs 202_1-202_3 is referred to as a service cycle SC. In the present embodiment, bandwidth allocation in the third service cycle SC is executed in advance during the current service cycle SC. This allocation in the third service cycle allows enough time for the processing.

FIG. **3** illustrates a way that three ONUs communicate with an OLT in the present embodiment. As already described, data processed by the first to third ONUs 202_1-202_3 is classified into three classes depending on the priorities. These classes of data include EF (Expedited Forwarding) data for guaranteeing a delay and a bandwidth, AF (Assured Forwarding) data for not guaranteeing a delay but guaranteeing a bandwidth, and BE (Best Effort) data for not guaranteeing a delay or a bandwidth. Headers of service cycles SC_1, SC_2, SC_3 . . . include time slots 241_1, 241_2, 241_3 . . . for the highest-priority EF data, respectively. Since the EF data is assigned the highest priority with being guaranteed a delay and a bandwidth, the bandwidth allocation is not controlled for the EF data. The bandwidth allocation is controlled for data of the AF class and the BE class. Prior to each of the service cycles SC_1, SC_2, and SC_3, the signal sending permissions 224_1-224_3 (G_1, G_2, and G_3) are sent from the OLT **201** to the first to third ONUs 202_1-202_3 at times t_{11}, t_{12}, and t_{13}.

For example, the first service cycle SC_1 is assigned a time slot 241_1 for the EF data first. Then, data D_1 of the AF class and the BE class based on a request by the first ONU 202_1 is transmitted to the OLT **201**. After the transmission, the output request (REPORT) 223_1 is transmitted from the first ONU 202_1 to the OLT **201** piggyback at the end of the data D_1. Then, data D_2 of the AF class and the BE class based on a request by the second ONU 202_2 is transmitted to the OLT **201**. After the transmission, an output request 223_2 is transmitted from the second ONU 202_2 to the OLT **201** piggyback at the end of the data D_2. Then, data D_3 of the AF class and the BE class based on a request by the third ONU 202_3 is transmitted to the OLT **201**. After the transmission, the output request 223_3 is transmitted from the third ONU 202_3 to the OLT **201** piggyback at the end of the data D_3.

The above transmission also applies to the second service cycle SC_2 and the third service cycle SC_3. However, the data D_1, D_2, and D_3 of the first to third ONUs 202_1-202_3 in respective service cycle SCs are not always transmitted in that order. For example, the data D_2, D_3, and D_1 are transmitted in that order after the time slot 241_1 for the EF data in the second service cycle SC_2. Similarly, the data D_3, D_1, and D_2 are transmitted in that order after the time slot 241_3 for the EF data in the third service cycle SC_3. This transmission, being set by shifting an allocation module for starting the processing in a cyclic manner for each service cycle, as described below. This setting provides equalized allocation among the ONUs.

FIG. **4** illustrates how three ONUs communicate with an OLT in a related art in contrast to the present embodiment. FIG. **4** is identical to FIG. **3** in that the time slots 241_1, 241_2, and 241_3 for the highest-priority EF data are located in the headers of the respective service cycles SC_1, SC_2, and SC_3. FIG. **4** is identical to FIG. **3** also in that prior to the respective service cycles SC_1, SC_2, and SC_3, at times t_{21}, t_{22}, and t_{23}, the signal sending permissions **124** (G_1, G_2, and G_3) are sent from the OLT **101** (see FIG. **11**) to the first to third ONUs 102_1-102_3 (also see FIG. **11**).

However, according to the related art shown in FIG. **4**, the data D_1, D_2, and D_3 of the first to third ONUs 102_1-102_3 in the respective service cycles SC_1, SC_2, and SC_3 are transmitted in that order. Additionally, after the last data D_3 is sent to the OLT **101** and the output request (REPORT) 123_3 by the third ONU 102_3 is sent to the OLT **101** piggyback, relatively long-time traffic allocations AL_1 and AL_2 are assigned. As a result, according to the related art shown in FIG. **4**, an amount of data D_1, D_2, and D_3, which can be transmitted to the OLT **101** in a time period of predetermined time length is small. The data transmission according to the embodiment of the present invention is more efficient.

The description is continued with referring back to FIG. **3**. Also in the present embodiment, the length of each of the service cycles SC_1, SC_2, and SC_3 does not need to be always constant. However, Maximum of Service Cycle is determined in advance for each service cycle SC and the allocation is performed so that a requested signal does not exceed the Maximum of Service Cycle. In the present embodiment, while the interface module **225** shown in FIG. **2** is performing the signal sending permissions 224_1-224_3 for the allocation in the service cycle SC_1, the first to third allocation modules 231_1-231_3 perform the allocation processing in the third service cycle SC_3. This allows enough time for the bandwidth allocation processing. As a result, the traffic allocations AL shown in FIG. **4** do not appear as intervals during which the data D cannot be transmitted, in the present embodiment.

In the present embodiment, the first allocation module **231** shown in FIG. **2** receives the queue state signal $\mathbf{226}_1$ based on a request by the first ONU $\mathbf{202}_1$. When the requested amount of data falls within the range of the Maximum of Service Cycle for the service cycle SC_3, the first allocation module $\mathbf{231}_1$ allocates a bandwidth to the data D_1 ($\mathbf{251}_1$ in FIG. **4**) of the AF class and the BE class requested. The first allocation module $\mathbf{231}_1$ passes an allocation result signal $\mathbf{232}_1$ to the second allocation module $\mathbf{231}_2$. An expression of AL(1/3)*3 shown in FIG. **3** indicates time for the above operation.

The queue state signal $\mathbf{226}_2$ based on a request by the second ONU $\mathbf{202}_2$ and the allocation result signal $\mathbf{232}_1$ sent from the first allocation module $\mathbf{231}_1$ are input to the second allocation module $\mathbf{231}_2$. If the requested amount of data falls within the range of the Maximum of Service Cycle for the service cycle SC_3, the data D_2 ($\mathbf{251}_2$ in FIG. **4**) of the AF class and the BE class as requested is allocated to a bandwidth. Then, the second allocation module $\mathbf{231}_2$ passes an allocation result signal $\mathbf{232}_2$ to the third allocation module $\mathbf{231}_3$. An expression of AL(2/3)*3 shown in FIG. **3** indicates time for the above operation.

A requested amount of data may not fall within the range of the Maximum of Service Cycle for the service cycle SC_3, when bandwidth is allocated. In this case, the second allocation module $\mathbf{231}_2$ performs the allocation by considering the result of the bandwidth allocation by the first allocation module $\mathbf{231}_1$ and the priorities of the classes. The allocation priority is expressed in the following equation (1):

$$\text{AF(the first ONU } 202_1\text{)>AF(the second ONU } 202_2\text{)>BE(the first ONU } 202_1\text{)>BE(the second ONU } 202_2\text{)} \quad (1)$$

That is, the AF data for the first ONU $\mathbf{202}_1$ is not changed, since a bandwidth of the AF data for the first ONU $\mathbf{202}_1$ is first allocated by priority in a bandwidth obtained by subtracting the time slot **241** for the EF data from the Maximum of Service Cycle for the service cycle. Since the priority of the AF data for the second ONU $\mathbf{202}_2$ is higher than the BE data for the first ONU $\mathbf{202}_1$, when the AF data for the second ONU $\mathbf{202}_2$ is allocated in remaining bandwidth and further remaining bandwidth is small, a bandwidth of the BE data for the first ONU $\mathbf{202}_1$ may be reduced by the AF data for the second ONU $\mathbf{202}_2$. If a bandwidth of the Maximum of Service Cycle for the service cycle is exceeded when the AF data for the first and second ONUs $\mathbf{202}_1$ and $\mathbf{202}_2$ is allocated, the BE data for the first and second ONUs $\mathbf{202}_1$ and $\mathbf{202}_2$ is not allocated a bandwidth.

If the total bandwidth to be allocated to the AF data for the first and second ONUs $\mathbf{202}_1$ and $\mathbf{202}_2$ exceeds the Maximum of Service Cycle, the AF data for the first ONU $\mathbf{202}_1$ is allocated a bandwidth as required, while the AF data for the second ONU $\mathbf{202}_2$ is allocated the remaining bandwidth within the range of the Maximum of Service Cycle. As described above, the priority of the bandwidth allocation among the first to third ONUs $\mathbf{202}_1$-$\mathbf{202}_3$ varies depending on the service cycles SC. Unlike the conventional embodiment shown in FIG. **4**, there is no need to equalize the bandwidth allocation among the respective service cycles SC.

When the above processing for the bandwidth allocation finishes, the second allocation module $\mathbf{231}_2$ passes the allocation result signal $\mathbf{232}_2$ to the third allocation module $\mathbf{231}_3$.

The queue state signal $\mathbf{226}_3$ based on a request by the third ONU $\mathbf{202}_2$ and the allocation result signal $\mathbf{232}_2$ sent from the second allocation module $\mathbf{231}_2$ are input to the third allocation module $\mathbf{231}_3$. If the requested amount of data falls within the range of the Maximum of Service Cycle for the service cycle SC_3, the data D_3 ($\mathbf{251}_3$ in FIG. **4**) of the AF class and the BE class is allocated to a bandwidth as requested. Then, the third allocation module $\mathbf{231}_3$ passes an allocation result signal $\mathbf{232}_3$ to a first allocation module $\mathbf{231}_1$. An expression of AL(3/3)*3 shown in FIG. **3** indicates time for the above operation.

A requested amount of data may not fall within the range of the Maximum of Service Cycle for the service cycle SC_3 when bandwidth is allocated. In this case, the third allocation module $\mathbf{231}_3$ performs the allocation by considering the result of the bandwidth allocation by the first and second allocation modules $\mathbf{231}_1$ and $\mathbf{231}_2$ and the priorities of the classes. The allocation priority is expressed in the following equation (2):

$$\text{AF(the first ONU } 202_1\text{)>AF(the second ONU } 202_2\text{)>AF(the third ONU } 202_3\text{)>BE(the first ONU } 202_1\text{)>BE(the second ONU } 202_2\text{)>BE(the third ONU } 202_3\text{)} \quad (2)$$

That is, also in this case, the AF data for the first to third ONUs $\mathbf{202}_1$-$\mathbf{202}_3$ is simply allocated within the range of the Maximum of Service Cycle considering the priority shown in the equation (2). When the above processing finishes, the third allocation module $\mathbf{231}_3$ outputs the allocation complete signal $\mathbf{227}_3$ to the interface module **225**. The interface module **225** detects through the allocation complete signal $\mathbf{227}_3$ that the first to third ONUs $\mathbf{202}_1$-$\mathbf{202}_3$ have completed all the bandwidth allocation. At this time, the interface module **225** outputs the signal sending permissions $\mathbf{224}_1$-$\mathbf{224}_3$ to the first to third ONUs $\mathbf{202}_1$-$\mathbf{202}_3$, respectively. FIG. **3** shows the signal sending permissions $\mathbf{224}_1$-$\mathbf{224}_3$ as the signal sending permission G_3 at a time close to the end of the second service cycle SC_2.

FIG. **5** illustrates transition of bandwidth allocation by each allocation module in bandwidth allocation control for the service cycle SC_3. The bracketed numbers (1) to (3) attached to the first to third allocation modules $\mathbf{231}_1$-$\mathbf{231}_3$ indicate the order of the bandwidth allocation. In this example, all the data D_1 and D_2 acquire bandwidth till the bandwidth allocation stage by the second allocation module $\mathbf{231}_2$ without restriction. At the bandwidth allocation stage by the third allocation module $\mathbf{231}_3$ in order to keep the AF data for the data D_3 within the Maximum of Service Cycle, assignment of the BE data for the data D_2 of lower priority is reduced.

When the bandwidth allocation control in the service cycle SC_3 ends as described above, the bandwidth allocation control for the service cycle SC_4 starts. At the start time, the interface module **225** shown in FIG. **2** sets the second allocation module $\mathbf{231}_2$ to a start position of the bandwidth allocation. Then, it allocates data of the AF class and the BE class within the range of the Maximum of Service Cycle. The third allocation module $\mathbf{231}_3$ that performs the second allocation performs the allocation by considering the result of the bandwidth allocation by the second allocation modules $\mathbf{231}_2$ and the priorities of the classes. The allocation priority is expressed in the following equation (3):

$$\text{AF(the second ONU } 202_2\text{)>AF(the third ONU } 202_3\text{)>BE(the second ONU } 202_2\text{)>BE(the third ONU } 202_3\text{)} \quad (3)$$

Finally, the first allocation module $\mathbf{231}_1$ performs the allocation by considering the result of the bandwidth allocation by the second and third allocation modules $\mathbf{231}_2$ and $\mathbf{231}_3$ and the priorities of the classes. The allocation priority is expressed in the following equation (4):

$$\text{AF(the second ONU } 202_2\text{)>AF(the third ONU } 202_3\text{)>AF(the first ONU } 202_1\text{)>BE(the second ONU } 202_2\text{)>BE(the third ONU } 202_3\text{)>BE(the first ONU } 202_1\text{)} \quad (4)$$

When the above processing ends, the first allocation module 231_1 outputs the allocation complete signal 227_1 to the interface module **225**. The interface module **225** detects through the allocation complete signal 227_1 that all the bandwidth allocation for the first to third ONUs 202_1-202_3 have been completed. At this time, the interface module **225** outputs the signal sending permissions 224_1-224_3 to the first to third ONUs 202_1-202_3, respectively.

FIG. **6** illustrates transition of bandwidth allocation by each allocation module in bandwidth allocation control in the service cycle SC_4. The bracketed numbers (1) to (3) attached to the first to third allocation modules 231_1-231_3 indicate the order of the bandwidth allocation. In this example, all the data D_1-D_3 are allocated bandwidth without restriction since the requested amount of data does not exceed the Maximum of Service Cycle even at the last bandwidth allocation stage by the first allocation module 231_1.

When the bandwidth allocation control in the service cycle SC_4 ends as described above, the bandwidth allocation control for the service cycle SC_5 starts. At the start time, the interface module **225** shown in FIG. **2** sets the third allocation module 231_3 to a start position of the bandwidth allocation. Then, it allocates data of the AF class and the BE class within the range of the Maximum of Service Cycle. The first allocation module 231_1 that performs the second allocation performs the allocation by considering the result of the bandwidth allocation by the third allocation modules 231_3 and the priorities of the classes. The allocation priority is expressed in the following equation (5):

$$\text{AF(the third ONU } 202_3\text{)}>\text{AF(the first ONU } 202_1\text{)}>\text{BE (the third ONU } 202_3\text{)}>\text{BE(the first ONU } 202_1\text{)} \tag{5}$$

Finally, the second allocation module 231_2 performs the allocation by considering the result of the bandwidth allocation by the third and first allocation modules 231_3 and 231_1 and the priorities of the classes. The allocation priority is expressed in the following equation (6):

$$\text{AF(the third ONU } 202_3\text{)}>\text{AF(the first ONU } 202_1>\text{AF (the second ONU } 202_2\text{)}>\text{BE(the third ONU } 202_3\text{)}>\text{BE(the first ONU } 202_1\text{)}>\text{BE(the second ONU } 202_2\text{)} \tag{6}$$

When the above processing of the bandwidth allocation ends, the second allocation module 231_2 outputs the allocation complete signal 227_2 to the interface module **225**. The interface module **225** detects through the allocation complete signal 227_2 that all the bandwidth allocation for the first to third ONUs 202_1-202_3 have been completed. At this time, the interface module **225** outputs the signal sending permissions 224_1-224_3 to the first to third ONUs 202_1-202_3, respectively.

FIG. **7** illustrates transition of bandwidth allocation by each allocation module in bandwidth allocation control in the service cycle SC_5. The bracketed numbers (1) to (3) attached to the first to third allocation modules 231_1-231_3 indicate the order of the bandwidth allocation. In this example, assignment of the BE data for the low-priority data D_1 is restricted since the Maximum of Service Cycle is exceeded at the second stage by the first allocation module 231_1. At the last stage of the bandwidth allocation by the second allocation module 231_2, the allocation is performed completely for the AF data of higher priority than the BE data. Accordingly, only BE data of the highest-priority data D_3 in the BE data is allocated bandwidth with a limit satisfying the Maximum of Service Cycle. The bandwidth of the BE data of the D_1 is used as bandwidth allocated to the AF data of the D_2.

In FIG. **7**, to allocate the bandwidth of the AF data of the D_2, allocated bandwidth of the BE data of the D_1 is replaced for bandwidth to be allocated to the AF data of the D_2. The BE data of the D_2 is not allocated, and only BE data of the D_3 is allocated with restriction. The allocation restriction method is not limited to the above, but bandwidth permitted for the BE data can be allocated by equally restricting the BE data of the D_1-D_3. (See FIG. **8**.)

FIG. **9** is a flow diagram illustrating an overview of bandwidth allocation control unit that performs the above described processing. In the processing, the first to Nth ONUs 202_1-202_N shown in FIG. **1** communicate with the OLT **201**. At step S**301**, the bandwidth allocation control unit **221** accepts the output requests 223_1-223_N in the first service cycle SC_1. The signal sending permissions 224_1-224_N are granted to the output requests 223_1-223_N, according to the conventional approach described in FIG. **12** or FIG. **13**. The permitted data of the data D_1-D_N of the first to Nth. ONUs 202_1-202_N are transmitted the OLT **201**. The bandwidth allocation control unit **221** controls the bandwidth allocation for the third service cycle SC_3 in advance.

To relieve the processing in the first service cycle SC_1, in the present embodiment, for the first service cycle SC_1, the bandwidth allocation control unit **221** receives the output requests 223_1-223_N, makes the ONUs 202_1-202_N to transmit data only of the EF class for guaranteeing a delay and a bandwidth, or makes the ONUs 202_1-202_N to transmit data containing bandwidth of the AF class and the EF class. Accordingly, the output requests 223_1-223_N, which contain mainly the BE class not transmitted in the first service cycle SC_1, are allocated to the third service cycle SC_3. The next allocation for the second service cycle SC_2 can be performed by providing the traffic allocation AL shown in FIG. **14** in the last interval in the first service cycle SC_1.

At the next step S**302** that executes the second service cycle SC_2, similarly to the first service cycle SC_1, the bandwidth allocation control unit **221** receives the output requests 223_1-223_N, and makes the ONUs 202_1-202_N to transmit data only of the EF class, or makes the ONUs 202_1-202_N to transmit data containing bandwidth of the AF class and the EF class. Alternatively, based on the traffic allocation AL performed in the first service cycle SC_1, the bandwidth allocation control unit **221** makes the ONUs 202_1-202_N to transmit the data D_1-D_N limited to the EF class and the AF class, and performs the allocation for the fourth service cycle SC_4. If there is enough time for the processing, the bandwidth allocation control unit **221** can make the ONUs 202_1-202_N to transmit all or some of the data D_1 to D_N of the BE class data that requested by the output requests 223_1-223_N.

At the next step S**303** that executes the third service cycle SC_3, the bandwidth allocation control unit **221** makes the ONUs 202_1-202_N to transmit the data D_1 to D_N allocated bandwidth at step S**301**, and executes the allocation for the fifth service cycle SC_5 in accordance with the output requests 223_1-223_N to be received from the first to Nth ONUs 202_1-202_N. Similarly, at the next step S**304** that executes the fourth service cycle SC_4, the bandwidth allocation control unit **221** makes the ONUs 202_1-202_N to transmit the data D_1 to D_N allocated bandwidth at step S**302**, and executes the allocation for the sixth service cycle SC_6 in accordance with the output requests 223_1-223_N to be received from the first to Nth ONUs 202_1-202_N. Subsequent allocations are performed in the same way as above.

FIG. **10** illustrates the control of the bandwidth allocation control unit in detail. In the diagram, the number of the ONU **202** is n. Each ONU **201** is indexed by 0, 1, 2, . . . and n−1. The service cycle SC is a cycle of 0 to n−1. First, the bandwidth allocation control unit **221** initializes a parameter i of the service cycle SC to 0 (step S**321**) before starting the processing, and initializes a parameter j to 0 (step S**322**). A parameter k of the allocation module **231** is set to the value (herein 0) of the parameter i (step S**323**), and a parameter l is initialized to 0 (step S**324**).

The allocation module $\mathbf{231}_k$ (herein the allocation module $\mathbf{231}_0$) of the bandwidth allocation control unit **221** performs allocation for an ONU $\mathbf{202}_k$ (herein ONU $\mathbf{202}_0$) in an ith service cycle SC_i (herein service cycle SC_0) (step S**325**). That is, the first allocation module $\mathbf{231}_1$ allocates the first bandwidth depending on the priority, as shown by (1) in FIG. **5** in the above example.

When the ONU $\mathbf{202}_k$ is allocated in this way, the allocation result is forwarded to the following allocation module $\mathbf{231}_{k+1}$ (step S**326**). Next, the parameter **1** is incremented by one (step S**327**) and the parameter k is incremented by one (step S**328**). The value of the parameter k cycles within the number of the ONUs **202**, i.e. n. That is, k is a residue system of n.

Next, it is checked whether the parameter **1** reaches to n (step S**329**). Each ONU **202** is allocated bandwidth depending the priority by going back to step S**325** till all bandwidth of n of ONUs **202** are allocated (step **329**: N). If the parameter **1** equals to n (step S**329**: Y), the parameter j is incremented by one (step S**330**) and the parameter i is incremented by one (step S**331**). The value of the parameter i cycles within the limit, the number of the ONUs **202**, n,

Finally, it is checked whether the parameter j reaches to n (step S**332**). If j is different from n (step **332**: N), the processing continues similarly by going back to step S**323**. If the parameter j equals to n (step S**332**: Y), the processing goes back to step S**321** (return).

Now, the present embodiment is compared with the conventional approach to allocate bandwidth after receiving the output requests (REPORTs) from all the ONUs **202** under control of the OLT **201**. According to the present embodiment, the output request from the ONU **202** are received in sequence and the bandwidth allocation processing is performed in two service cycles ahead, so that special time does not need to be set for allocation, and service cycles after the third service cycle does not waste bandwidth. Additionally, since the bandwidth allocation order changes in a cyclic manner, the bandwidth allocation processing is simplified and equalization among the ONUs **202** is ensured. Furthermore, according to the present embodiment, the distributed processing by each ONU allows sufficient time for processing, and the control unit is not assigned excessive loads if the number of the ONUs increases. The present example has an advantage that the processing speed is high enough, and an inexpensive circuit element or CPU can constitute the control unit, whereby saving the system cost.

Although the bandwidth allocation is processed by classifying the priorities to three classes of EF, AF and BE in the above described embodiment, the priority classification criteria or the number of the classes should not be limited to the embodiment. For example, it is possible to classify the AF into first relatively high-priority AF and second relatively low-priority AF, and similarly classify the BE to first and second BEs. According to this example, the relation among the priorities service cycles to allocate bandwidth in the order of the second ONU, the third ONU, and the first ONU is shown in the following equation (7):

first AF(second ONU)>first AF(third ONU)>first AF(first ONU)>second AF(second ONU)>second AF(third ONU)>second AF(first ONU)>first BE(second ONU)>first BE(third ONU)>first BE(first ONU)>second BE(second ONU)>second BE(third ONU)>second BE(first ONU) (7)

The previous description of embodiments is provided to enable a person skilled in the art to make and use the present invention. Moreover, various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles and specific examples defined herein may be applied to other embodiments without the use of inventive faculty. Therefore, the present invention is not intended to be limited to the embodiments described herein but is to be accorded the widest scope as defined by the limitations of the claims and equivalents.

Further, it is noted that the inventor's intent is to refrain all equivalents of the claimed invention even if the claims are amended during prosecution.

What is claimed is:

1. A bandwidth allocation equipment in an optical line terminal which allocates bandwidth for data to be transmitted from a plurality of optical network units through an optical splitter, said equipment comprising:

a transmit/receive unit that receives an output request for requesting bandwidth allocation to the data from the respective optical network units, and sends back a signal sending permission to the respective optical network units for specifying bandwidth to be allowed for transmitting the data in each service cycle as a unit period for the data transmission; and

a plurality of bandwidth allocation units, each bandwidth allocation unit is provided with corresponding to the optical network unit for performing bandwidth allocation processing in accordance with the output request for the data to be transmitted from the corresponding optical network unit, and each of bandwidth allocation units are connected to one another in a ring to perform the bandwidth allocation processing one by one for corresponding optical network unit, and outputs the signal sending permission to the transmit/receive unit from the bandwidth allocation unit that has performed the last bandwidth allocation processing in the ring connection,

wherein, said transmit/receive unit specifies the bandwidth allocation unit that performs the first bandwidth allocation processing by shifting the bandwidth allocation unit one by one for each of the service cycles.

2. The bandwidth allocation equipment according to claim **1**, wherein

said bandwidth allocation unit, other than those which performs the bandwidth allocation processing at first and at last in the ring connection, performs the bandwidth allocation processing by taking over bandwidth allocation result having been performed by preceding bandwidth allocation unit in conjunction with the output request of the corresponding optical network unit, and sends the bandwidth allocation result having been performed by own bandwidth allocation unit to succeeding bandwidth allocation unit in the ring connection.

3. The bandwidth allocation equipment according to claim **2**, wherein

said data to be transmitted from the optical network unit is classified into one of priorities for transmission, and said bandwidth allocation unit allocates bandwidth to each data in accordance with the priority.

4. The bandwidth allocation equipment in the optical line terminal according to claim **3**, wherein

said priorities are classified into a plurality of classes including a class for guaranteeing a delay and a bandwidth, and a class for not guaranteeing a delay or a bandwidth for data sent from said optical network unit to said transmit/receive unit.

5. The bandwidth allocation equipment according to claim **3**, wherein said data handled by the bandwidth allocation unit which performs the bandwidth allocation processing in first in the ring connection has higher priority than the data having the same priority handled by the bandwidth allocation unit which performs the bandwidth allocation processing later in the ring connection.

6. The bandwidth allocation equipment according to claim **5**, wherein

said bandwidth allocation unit allocates bandwidth by replacing the bandwidth for data having been allocated in the previous bandwidth allocation result by data of a higher-priority within a range of a maximum bandwidth allowed for the service cycle.

7. The bandwidth allocation equipment in the optical line terminal according to claim **3**, wherein

said bandwidth allocation unit allocates equally each data of a class of the optical network unit to a class of a priority that can allocate some data to the maximum bandwidth allowed for a service cycle.

8. The bandwidth allocation equipment according to claim **2**, wherein

said bandwidth allocation unit performs the bandwidth allocation processing for a service cycle at least two service cycle ahead of the service cycle that accepts said output request.

9. A bandwidth allocation method in an optical line terminal which allocates bandwidth for data to be transmitted from a plurality of optical network units through an optical splitter, said method comprising:

an output request receiving step that receives an output request for requesting bandwidth allocation to the data from the respective optical network units;

a bandwidth allocation processing step that performs bandwidth allocation by a plurality of bandwidth allocation units, each bandwidth allocation unit is provided with corresponding to the optical network unit for performing bandwidth allocation processing in accordance with the output request for the data to be transmitted from the corresponding optical network unit, and each of bandwidth allocation units are connected to one another in a ring to perform the bandwidth allocation processing one by one for corresponding optical network unit; and

a sending back step that sends back a signal sending permission, which has been output from the bandwidth allocation unit that has performed the last bandwidth allocation processing in the ring connection, to the respective optical network units for specifying bandwidth to be allowed for transmitting the data in each service cycle as a unit period for the data transmission,

wherein, said bandwidth allocation processing step includes a bandwidth allocation unit specifying step that specifies the bandwidth allocation unit to perform the first bandwidth allocation processing in the ring connection by shifting the bandwidth allocation unit one by one for each of the service cycles.

10. The bandwidth allocation method according to claim **9**, wherein

said bandwidth allocation processing step includes a bandwidth allocation result taking over step to be performed by the bandwidth allocation unit, other than those which performs the bandwidth allocation processing at first and at last in the ring connection, that performs the bandwidth allocation processing by taking over bandwidth allocation result having been performed by preceding bandwidth allocation unit in conjunction with the output request of the corresponding optical network unit, and sends the bandwidth allocation result having been performed by own bandwidth allocation unit to succeeding bandwidth allocation unit in the ring connection.

11. The bandwidth allocation method according to claim **10**, wherein

said data to be transmitted from the optical network unit is classified into one of priorities for transmission, and said bandwidth allocation unit allocates bandwidth to each data in accordance with the priority in said bandwidth allocation processing step.

12. The bandwidth allocation method according to claim **11**, wherein

said bandwidth allocation processing step includes a bandwidth replacing step that replaces the bandwidth for data having been allocated in the previous bandwidth allocation result by data of a higher-priority within a range of a maximum bandwidth allowed for the service cycle.

13. The bandwidth allocation method according to claim **10**, wherein

said bandwidth allocation processing step is performed for the bandwidth allocation for a service cycle at least two service cycle ahead of the service cycle that accepts said output request.

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